LA-UR-19-25145
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Title: Improving prediction of radioactive gas seepage for nuclear testing treaty verification

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Intended for: Science Highlight

Issued: 2019-06-05

Improving prediction of radioactive gas seepage for nuclear testing treaty verification

The length of time it takes for radioactive gases to seep from an underground nuclear test to the ground surface is crucial for verification of nuclear testing treaties, such as the Comprehensive Nuclear Test Ban Treaty (CTBT). The identification of short-lived radioactive gases emanating from the ground surface at a suspected nuclear test location could provide "smoking gun" type evidence of a nuclear test. Accurate predictions of radioactive gas arrival time and detection window (duration of time gas concentration is above its detection threshold) are critical for procuring this type of evidence. LANL researchers are working toward improving such predictions in support of the Global Security mission and Information Science & Technology science pillar.

Accurately predicting radioactive gas arrival time and detection window is complicated by many factors including rock properties at the site; existence of natural fractures, faults, and blast induced fractures; barometric variations (changes in atmospheric pressure produce oscillatory flow into and out of fractured rock); depth of burial; nuclear device yield; topography; degree of saturation of the rock; etc. These factors influence the processes of radioactive gas diffusion, dissolution, and volatilization (depicted in Figure 1) which control the rate of gas seepage toward the ground surface during barometric pressure oscillations.

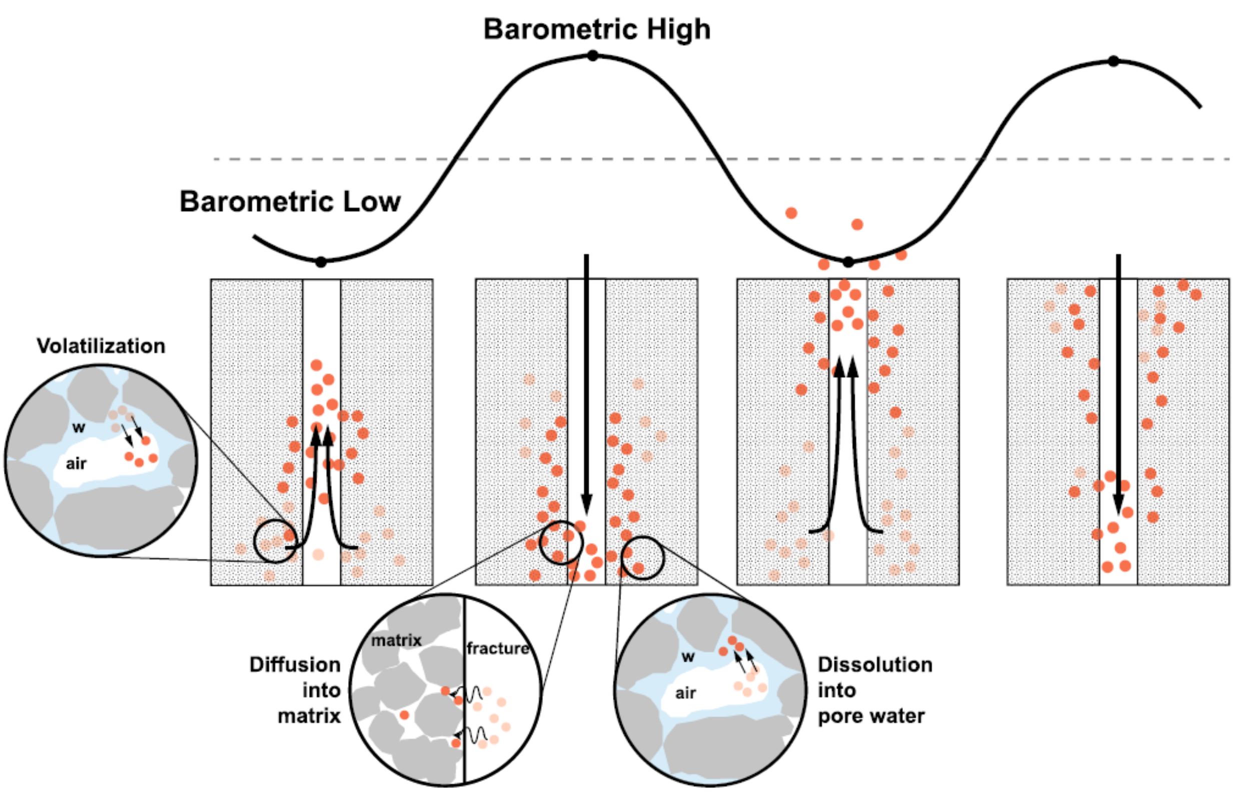

Figure 1. Schematic of gas transport through a fracture subjected to variation in barometric pressure. Cutouts illustrate the processes of dissolution, volatilization and diffusion into the matrix.

In a recent publication (Harp et al., 2018), scientists in the Earth & Environmental Sciences (EES) division revealed the importance of gas solubility in accurately predicting gas seepage. Gases flowing through the subsurface dissolve into the water that occupies void spaces in rock (pore water) up to their solubility limit, or point at which gas concentrations in the air and water are in equilibrium. When gas concentrations are out of equilibrium, the dual processes of dissolution (gas dissolving from air into water) and volatilization (gas escaping water into air) bring the concentrations back into equilibrium. The rate at which this dissolution occurs is variable depending on the gases free air and water diffusion coefficients, interfacial area between air and water present in the void spaces of the subsurface, the width of the boundary layer across which dissolution occurs, salinity, temperature, etc.

Harp et al. (2018) discovered through numerical investigations that the rate of dissolution, specific to a given gas, can have a large impact on the arrival time and detection window of radioactive gases at the ground surface. They compare rates of gas transport to the ground surface under simulations both with and without pore water for various dissolution rates, gas diffusion rates, and degrees of saturation. Their findings indicate that gases with higher dissolution rates have enhanced rates of transport and shorter arrival times in the presence as compared to the absence of pore water (Fig. 2, top). Gases with lower dissolution rates, on the other hand, have retarded rates of transport and longer arrival times in the presence as compared to the absence of pore water (Fig. 2, bottom). This enhanced or delayed transport is maximized at higher degrees of gas saturation within the rock. These results suggests that predictions of radioactive gas arrival time and detection window at suspected nuclear test locations should incorporate the role of rate-limited pore water storage in enhancing or retarding gas transport.

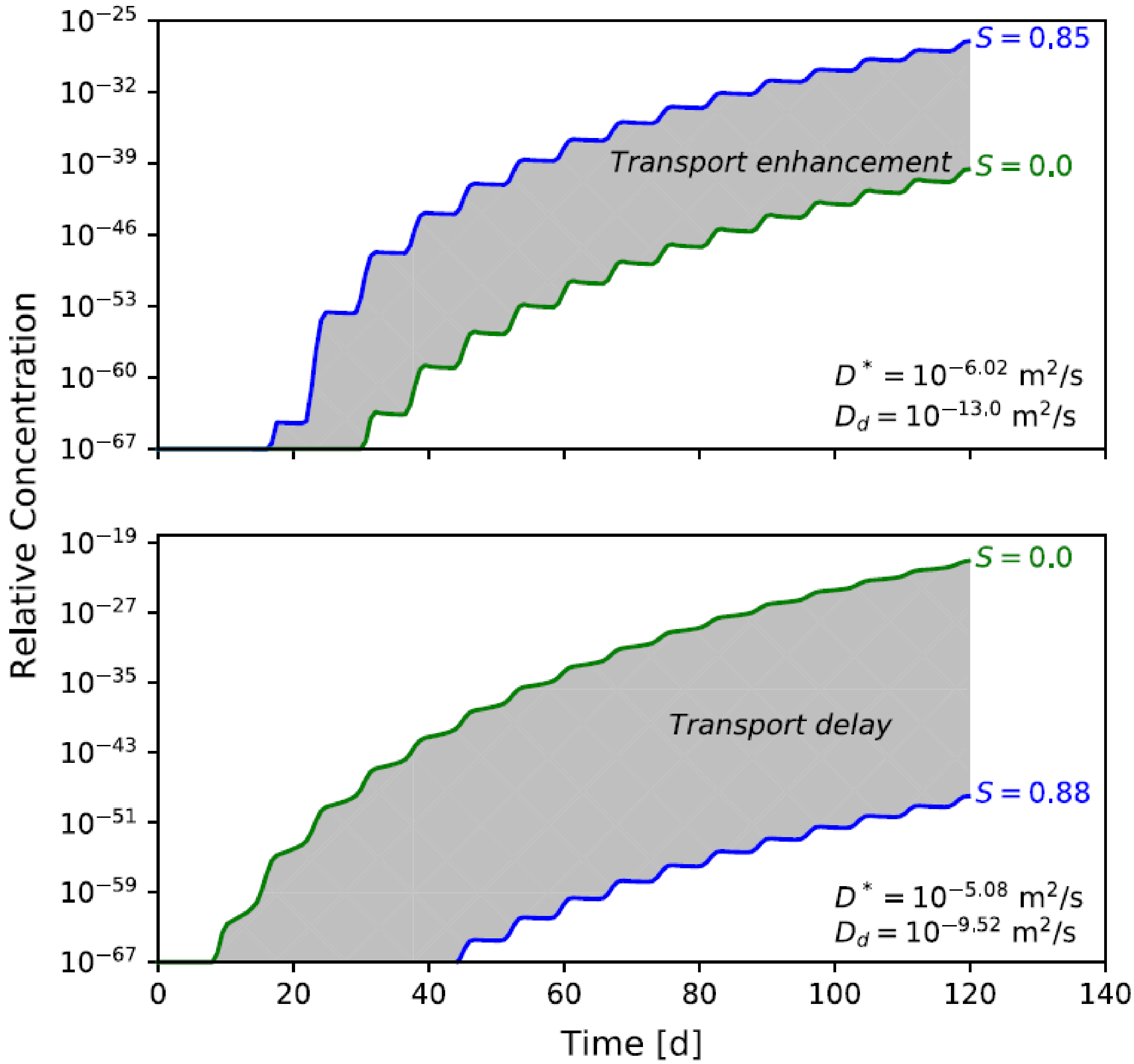

Figure 2: Time series of relative gas concentrations in a fracture at the ground surface under cases of greatest transport enhancement (top) and delay (bottom) due to the presence of pore water. The gas diffusion coefficient (D^*) and dissolution coefficient (D_d) are noted in the bottom right of each plot. The blue lines are concentrations with pore water, while the green lines are concentrations for associated simulations without pore water. The degree of gas saturation (S) is indicated at the end of each line (saturation is zero for simulations without pore water). The gray shaded region indicates the amount of enhancement or delay due to the presence of pore water.

Reference: "Immobile pore-water storage enhancement and retardation of gas transport in fractured rock." 2018. Transport in Porous Media, https://doi.org/10.1007/s11242-018-1072-8. LA-UR-18-24094. Dylan Harp (Computational Earth Science, EES-16), John Ortiz (EES-16), Sachin Pandey (EES-16), Satish Karra (EES-16), Dale Anderson (Geophysics, EES-17), Chris Bradley (EES-17), Hari Viswanathan (EES-16), and Phil Stauffer (EES-16).

Funding for this work was provided by National Nuclear Security Administration Office of Defense Nuclear Nonproliferation Research and Development and the Defense Threat Reduction Agency, the Los

Alamos National Laboratory Institutional Computing Program, and the U.S. Department of Energy.
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